VALIDATION OF THE eCALC COMMERCIAL CODE-COMPLIANT SIMULATION VERSUS MEASURED DATA FROM AN OFFICE BUILDING IN A HOT AND HUMID CLIMATE

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ABSTRACT

This paper compares the results of a calibrated simulation of a case-study building versus simulation using the web-based eCALC code-compliant commercial simulation program (Haberl et al., 2004). Previously, as-built calibrated simulation results for the case-study building were performed and reported in Cho and Haberl (2008). In this paper an extension of the previous work is presented using the eCALC commercial simulation model, which uses simplified geometry and ASHRAE Standard 90.1-compliant equipment selection and sizing values for energy calculation. This paper compares the results between the as-built geometry simulation and simplified geometry simulation with similar equipment configuration. The simplified geometry simulation model is a modified-eCALC DOE-2 model that includes simplifications of the case-study building's characteristics. The modified-eCALC DOE-2 model was intended to be used for the development of an easy-to-use tool for the selection of high-performance systems for office buildings in hot and humid climates, which will be presented in another publication.

OVERVIEW OF THE eCALC PROGRAM

The eCALC program, a web-based NOx, Sox, and CO_2 emissions calculator developed by the Energy Systems Laboratory (ESL), consists of four major components. As shown in Figure 1, the components are: 1) a web interface, 2) a calculation engine, 3) a weather database, and 4) a general project/operations database. The functions of the four elements are (Haberl et al., 2004):

1) Web interface: Interacts with users and receives general project information from users.
2) Weather database: Contains 1999 TRY (Test Reference Year) weather data for locations in Texas.
3) General project/operations database: Consists of XML (Extensible Markup Language) that supports a wide variety of applications and SQL (Structured Query Language) that creates, retrieves, updates, and deletes data from relational database management systems.
4) Calculation engine: Obtains information from users along with other information from the calculator's libraries. Then, the calculator transmits their information into one of the legacy programs. The legacy programs and their functions are:
   a. DOE-2: Building energy simulation analysis (LBNL, 1981).
   b. F-Chart: Solar thermal systems analysis (Beckman et al., 1977).
   c. PV F-Chart: Solar Photovoltaic (PV) systems analysis (Klein and Beckman, 1983).
   d. ASHRAE IMT: Monthly utility billing analysis for the analyses of the monthly municipal, traffic light, water, waste-water, and wind energy (Kissock et al., 2002).
   e. Peak-extractor: Extracting the peak day use from DOE-2 simulations or the coefficients that can drive the peak day use.

After the annual and peak-day savings are calculated, the results are compared with the US EPA's eGRID database (EPA, 2008) that includes detailed emissions data for the electric utility suppliers associated with the users. The emissions calculator calculates the NOx, SOx and CO_2 emissions produced by the power plants that provided the building's electricity use using the eGRID database. These results (energy and emissions savings) are then conveyed to the users as HTML (Hyper Text Markup Language) and XML (Extensible Markup Language) files through email.

Figure 2 shows an example of the information flow of the eCALC analysis process for commercial buildings. A user selects a type of commercial building and enters input parameters. The DOE-2 engine in the eCALC program then runs based on the pre-defined and code-compliant building characteristics (ASHRAE Standard 90.1-1999) using the weather data for the location of the user's target building. Next, the user's building description input is compared with pre-code values (ASHRAE 90.1-1989) and code-compliant values (ASHRAE 90.1-1999).

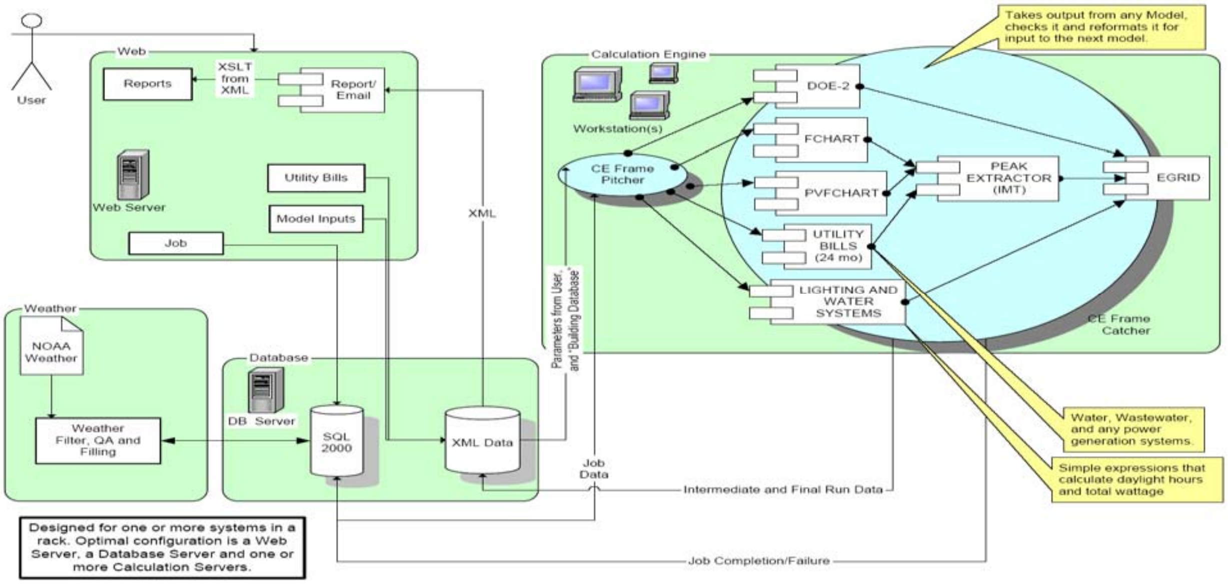


Figure 1. Block Diagram Showing Interactive-Functionality of the eCALC (Haberl et al., 2004)

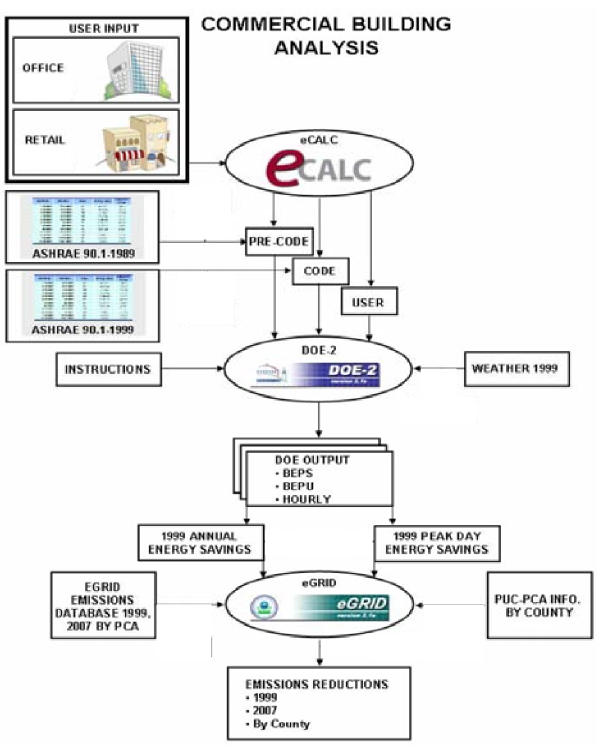


Figure 2. Example Flow Chart for Office Building Analysis (Haberl et al., 2004)

The DOE-2 program creates three output files for each simulation; one for pre-code simulation, one for the code-compliant simulation, and one for the user-defined building simulation. Then, the emissions calculator calculates the NOx, SOx and CO2 emissions using the eGRID database. These results (energy and emissions savings) are then conveyed to the user as HTML and XML files through email.

CASE STUDY BUILDING DESCRIPTION

<u>John B. Connally (JBC) Building</u>

The John B. Connally (JBC) building is one of the Texas A&M University facilities in College Station, Texas. The building picture and DrawBDL output of DOE-2 input file for the case study building are shown in Figure 3. This building consists of 124,000 square feet of conditioned space with seven stories and a thermal plant, which is detached from the building. This building is used for offices and conference rooms. The JBC building has a window-to-wall ratio of 40%.

<u>JCB Building's AHU Systems</u>

There are a total of nineteen (19) Air Handling Units (AHUs) of which seventeen are Single-Duct, Variable Air Volume (SDVAV) AHUs with Variable

Frequency Drives (VFDs). Two (2) AHUs are SDVAV outside AHUs, which provide 100% of the

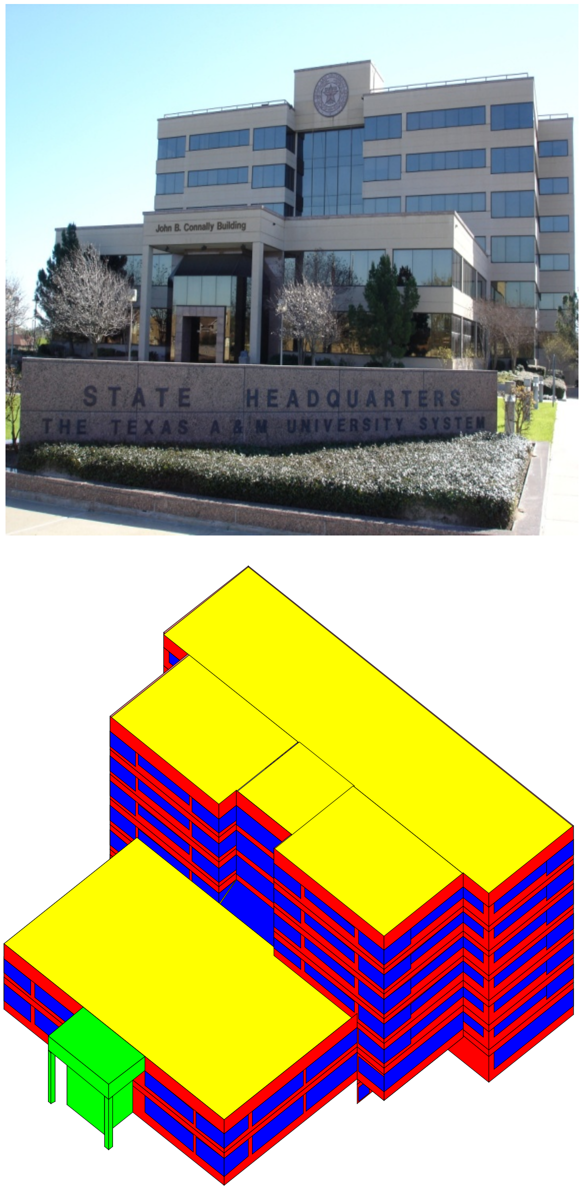


Figure 3. Case Study Building: John B. Connally Building (Picture & DrawBDL)

outside air to the seventeen (17) SDVAV AHUs. The two outside air AHUs are located on the roof of the building. The SDVAVs, as shown in Figure 4, are equipped with a cooling coil and a draw-through supply air fan. The mechanical rooms are used as mixing air chambers. Return air comes through the plenum on each floor, which is connected to the mechanical rooms. The return air is mixed with the outside air, which comes into the mechanical room through ducts from the OAHUs (Outside Air Handling Units) on the roof. The mixed air in the mechanical rooms comes into the AHUs and passes through the cooling coils.

In the building, there are 230 terminal VAV boxes, which have hot water reheat coils and supply air dampers that are run by Direct Digital Control (DDCs) systems. Also, there are nine (9) cooling fan coil units in several places such as the electrical room and the mechanical penthouses.

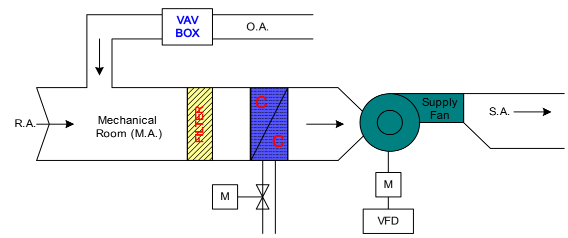


Figure 4. AHU System Diagram in the JBC Building

JCB Building's Thermal Plant

The thermal plant has two chillers providing chilled water for space cooling, two boilers providing hot water for space heating, and one water heater for service water heating. The two centrifugal chillers have a capacity of 280-ton each. The JBC building only needs one 280-ton chiller to meet the building's maximum cooling loads during occupied hours. The chillers are sequenced to allow both to run equal amounts each year. There are two 20 HP (Horse Power), constant speed chilled water pumps. These pumps operate only when their corresponding chillers are running. Two cooling towers are located right next to the thermal plant, which have a condensing water flow of 840 gallons per minute each. Each cooling tower has a 15 HP fan, which is a draw-through fan installed on the top of the cooling tower and is controlled by a VFD system. In a similar fashion as the chilled water pumps operate, these cooling towers also work when their associated chillers are running. The plant also contains two hot water boilers, which are gas-fired (80% efficiency) boilers with an input capacity of 2,000 MBtu/hr each.

JCB Building's Energy Use in 2006

The measured electricity consumption data were retrieved from the data logger installed in the JBC building. The electricity channels are Whole-Building Electricity (WBE), Lighting & Equipment (L&E), and chiller electricity use. Figure 5 shows daily electricity use for WBE, L&E, and chiller, which were obtained by summing and averaging the collected hourly data. The total WBE use was 2,669

MWh in 2006, which is the sum of chiller electricity use and Lighting & Equipment electricity use.

The monthly Natural Gas (N.G.) consumption of the JBC building was obtained from the utility provider. The total N.G. consumption of the JBC building was 817 MBtu in 2006 as shown in Figure 6. The JBC building went through a commissioning process in 2003 by engineers in the Energy Systems Laboratory at Texas A&M. Before the commissioning, the building consumed electricity of 2,879 MWh (EUI (Energy Use Index) of 23.22 kWh/sqft-yr) and 40,960 therms (EUI of 33.03 kBtu/sqft-yr).

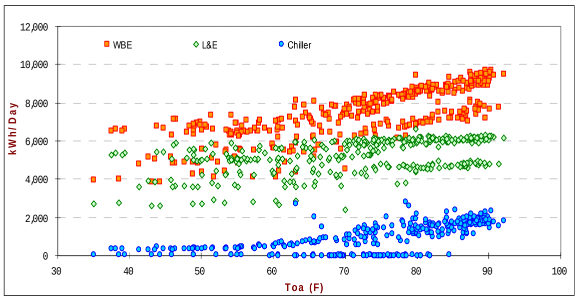
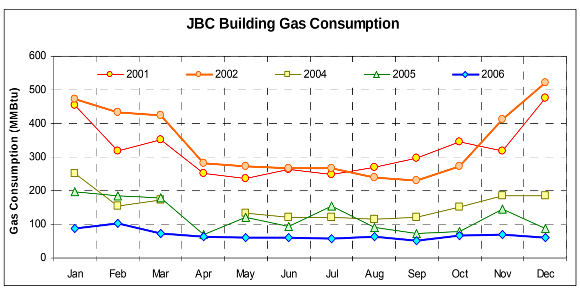


Figure 5. Measured Uses of WBE, L&E, and Chiller in 2006



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2001	454	317	351	253	236	264	247	269	297	345	318	477	3,828
2002	474	432	424	283	273	267	267	239	231	274	412	520	4,096
2003	Commissioning												
2004	212	252	156	173	153	133	121	122	115	122	151	186	1,896
2005	186	196	186	180	70	120	93	155	92	72	79	147	1,576
2006	87	103	74	63	62	60	58	63	51	66	69	61	817

Figure 6. N.G. Consumption Changes of the JBC Building Before and After Commissioning

After the commissioning process, the JBC building's electric consumption dropped by 10%. However, as shown in Figure 6, the N.G. use dropped significantly to less than half of the 2004 use. Additional changes were made in 2005 and 2006 that reduced this further. One major change during the commissioning on the boilers was a reset of the constant boiler temperature, which used to be 180 °F year round. According to the observation of site visits in 2006, the boilers for space heating were shut off all the time and the service water heater seemed to be the only source for using natural gas. As a result, the natural gas energy use was a small amount compared to the WBE and CHW energy use. Therefore, the WBE and CHW energy uses were main points of interest in this study.

AS-BUILT DOE-2 CALIBRATED SIMULATION OF THE JBC BUILDING

To develop a calibrated simulation model for the JBC building, three calibrated simulation methodologies were utilized, which include manual and iterative calibrations, graphical and statistical analysis, and a signature analysis. As presented in detail in the previous publication (Cho and Haberl, 2008), the main calibration points were: 1) 2006 TRY weather file created for College Station, TX, 2) typical load shapes of the measured lighting and equipment (Abushakra et al., 2001), 3) supply air temperature reset, 4) room air temperature reset, and 5) chiller efficiency curves from measured data. More detailed DOE-2 input parameters and step-by-step results of the calibrated simulation process were illustrated the previous publication (Cho and Haberl, 2008).

Figure 7 shows the final calibration results. The upper left graph compares the daily WBE use between the simulation results and the measured data along with the residuals. The upper right graph compares the daily CHW uses as the same fashion. The lower left and right are calibration signatures showing how much the simulation results and measured data disagree.

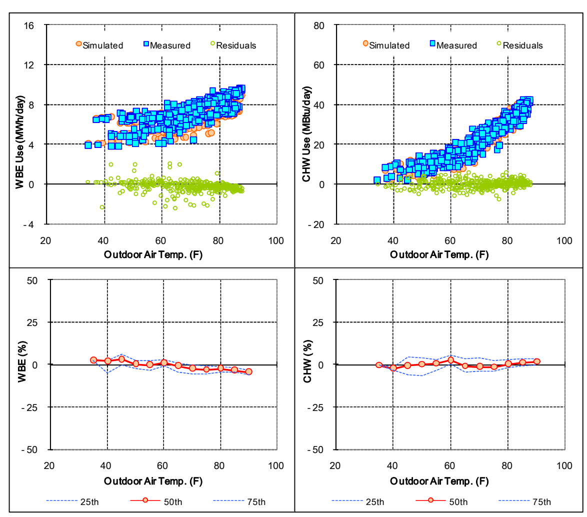


Figure 7. Calibration Results vs. Measured WBE and CHW Use (Upper) and Calibration Signature (Lower) for WBE and CHW

The final uncertainties of the simulation were CV(RMSE) (Coefficient of Variance of Root Mean Square Error) of 8.4% (WBE) and 9.8% (CHW). These error values are well below the tolerance range that ASHRAE published (ASHRAE, 2002), which is a 30% CV(RMSE).

Figure 8 shows the CV(RMSE) errors for the basecase and for the five calibrations. The chilled water consumption changed the most by changing the weather file from TMY2 (Typical Meteorological Year) to 2006 TRY for College Station, TX, although the WBE did not change much. In the WBE calibration, the use of diversity factors for internal heat gain schedule was the largest impact as shown in the graph (Calibration 1 to Calibration 2).

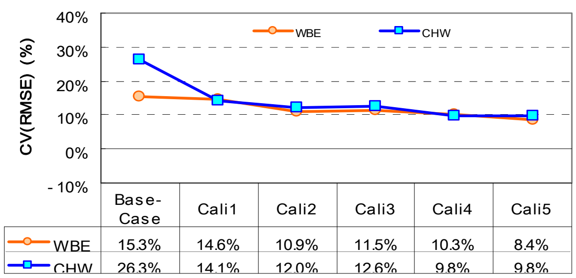


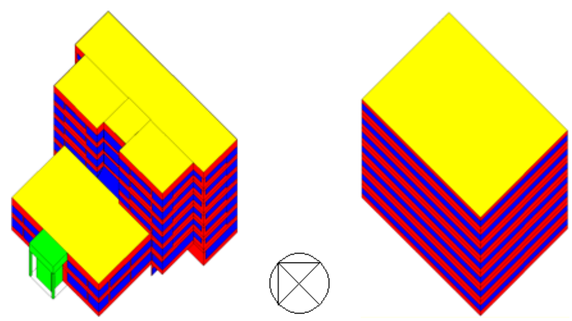
Figure 8. Summary of CV(RMSE) Changes

eCALC DOE-2 SIMULATION OF THE JBC BUILDING

The eCALC DOE-2 simulation program, as mentioned earlier, runs based on the pre-defined and code-compliant building characteristics using the weather data for the location where the user's target building is located. However, to input the same values used in the As-Built calibrated simulation, the office building DOE-2 input file in the eCALC program was modified to match the JBC building's LOADS simulation, SYSTEMS simulation, and PLANT simulation characteristics. The main changes in the eCALC DOE-2 input file were input parameters and schedules from ASHRAE 90.1-1999 minimum requirements to measured characteristics of the JBC building. All the input parameters used in the final As-Built DOE-2 calibrated simulation model were incorporated into the eCALC DOE-2 simulation input file.

One of the main differences between two simulation models is the building geometry. The As-Built DOE-2 model used real building geometries obtained from the architectural drawings and photographs. However, as a simplified simulation program, the eCALC DOE-2 model runs with box-shaped simplified geometry. Figure 9 shows two different building geometries: (a) as-is geometry used for the AS-Built DOE-2 simulation (b) simplified box-shaped building geometry for the eCALC DOE-2 simulation. The total conditioned space and window wall areas are the same for both cases.

Table 1 through Table 5 show the input values for the eCALC DOE-2 simulation. The simulation of the eCALC DOE-2 model used the aspect ratio of 1.4:1 (width:depth), which is equivalent to the shape of the JBC building. Figure 10 shows the results of the eCALC DOE-2 simulation for the JBC building. The errors (CV(RMSE)) from the As-Built calibrated simulation were 7.8% (WBE) and 8.3% (CHW), while those from the simplified geometry Modified-eCALC DOE-2 model were 7.7% (WBE) and 8.4% (CHW).



(a) (b)

Figure 9. Comparison of Building Geometries Showing (a) As-Built Building Geometry and (b) Simplified Box-Shaped Building Geometry

Table 1. Building General Inputs and U-Values

DOE-2 Keywords	Input Values	Description
LATITUDE	30.35 N	From NOAA
LONGITUDE	96.22 W	From NOAA
ALTITUDE	326 ft	From NOAA
AZIMUTH	90 Degree	Facing West
WALL-EXTERIOR	0.105	Btu/hr-sf-F
WALL-INTERIOR	0.339	Btu/hr-sf-F
ROOF	0.034	Btu/hr-sf-F
FLOOR-INTERNAL	0.230	Btu/hr-sf-F
UNDERGROUND	0.011	Btu/hr-sf-F
CEILING	0.562	Btu/hr-sf-F

Table 2. Glazing Properties

DOE-2 Keywords	Input Values	Description
LAYER	Exterior Lite	1/4" PPG Solarcool Bronze
	1/2" Cavity	1/2" Air
	Interior Lite	1/4" Clear Glass
U-VALUES	0.50/0.48	Summer/Winter (Btu/hr-sf-F)
SHGC	0.34	Solar Heat Gain Coefficient
SC	0.40	Shading Coefficient

Table 3. Space Conditions Input

DOE-2 Keywords	Input Values	Description
TEMP	74 F	Avg. Measured Value
AREA/PERSON	492 sq-ft/person	124,000 sqft / 252 people
PEOPLE-HG-SENS	245 Btu/hr	ASHRAE Fundamental
PEOPLE-HG-LAT	155 Btu/hr	ASHRAE Fundamental
LIGHTING-TYPE	REC-FLUOR-RV	Recessed Fluorescent Vented to Return Air
LIGHTING-W/SQFT	1.90 W/sq-ft	Measured (ASHRAE RP-1093)
LIGHT-TO-SPACE	0.80 (80%)	REC-FLUOR-RV
EQUIPMENT-W/SQFT	1.07 W/sq-ft	Measured (ASHRAE RP-1093)
FLOOR-WEIGHT	70 lb/sq-ft	DOE2 default (Medium)

Table 4. SYSTEMS Input Summary

DOE-2 Keywords	Input Values	Description
HEAT-TEMP-SCHEDULE	74 F	ZONE-CONTROL
COOL-TEMP-SCHEDULE	74 F	
SYSTEM-TYPE	VAVS	SYSTEM
RTN-AIR-PATH	PLENUM	
MIN-SUPP-TEMP	55F	SYSTEM-CONTROL
COOL-SET-TEMP	55F	
HEAT-SET-TEMP	105F	
MIN-OUTSIDE-AIR	0.07	SYSTEM-AIR
OA-CONTROL	FIXED	

SUPPLY-STATIC	2 in H2O	SYSTEM-FAN
FAN-CONTROL	SPEED	
MIN-CFM-RATIO	0.3	SYSTEM-TERMINAL
REHEAT-DELTA-T	48F	

Table 5. PLANT Input Summary

DOE-2 Keywords	Input Values	Description
HW-BOILER	2 x 1.2	1.2 MBtu/Hr
CENT-CHILLER	2 x 280 TON	3.4MBtu/Hr
COOLING TOWER (OPEN)	2 x 4.2	Mbtu/Hr
	Variable Speed	Tower Control

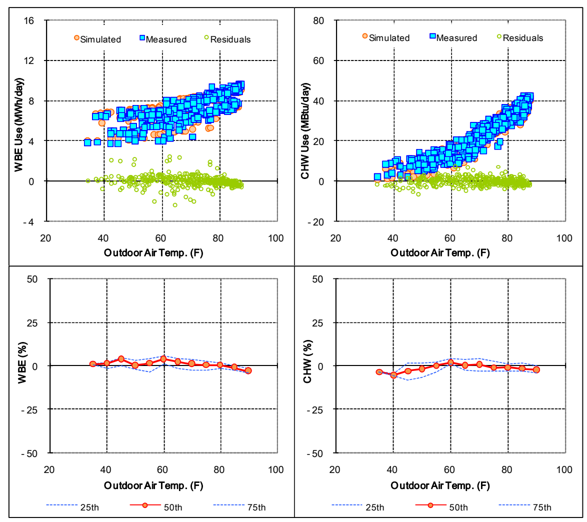


Figure 10. eCALC DOE-2 Simulation Results vs. Measured WBE and CHW Use (Upper) and Calibration Signature (Lower) for WBE and CHW

COMPARISON OF SIMULATION RESULTS (AS-BUILT MODEL VS. eCALC MODEL)

Table 6 shows the summary of the results from the two different simulations including uncertainties. As-Built DOE-2 simulation showed a WBE use of 2,632 MWh in 2006, which was 1.4% less than the measured WBE of 2,669 MWh. The eCALC DOE-2 simulation showed a WBE of 2,681 MWh, which was 0.4% more than the measured WBE. Both the As-Built and eCALC DOE-2 simulations were within ASHRAE's simulation error range of 30% (ASHRAE, 2002) with the As-Built DOE-2 simulation showing a CV(RMSE) of 7.8% and the eCALC DOE-2 simulation showing a 7.7%. The

WBE use deviation between As-Built and eCALC simulation models was 49 MWh, which is a MBE (Mean Bias Error) of 1.8%.

The CHW use from the As-Built DOE-2 simulation was 8,532 MBtu in 2006, which was 0.5% higher than that of measured data of 8,489 MBtu. The eCALC DOE-2 simulation showed a CHW use of 8,416 MBtu, which was 0.9% lower than that of the measured CHW use. The CV(RMSE) of both the As-Built and eCALC simulations were within the ASHRAE tolerance range with the As-Built DOE-2 simulation showing a CV(RMSE) of 8.3% and the eCALC DOE-2 simulation showing a CV(RMSE) of 8.4%. The CHW use deviation between As-Built and eCALC simulation models was 117 MBtu, which is a MBE of 1.4%.

Table 6. Energy Consumption Comparisons Between As-Built DOE-2 Simulation and eCALC DOE-2 Simulation

Comparison	Energy Type	WBE	CHW
	(Unit)	(MWh/yr)	(MBtu/yr)
Measurement	Energy Use	2,669	8,489
As-Built DOE-2 Calibrated Simulation	Energy Use	2,632	8,532
	MBE (%)	-1.4%	0.5%
	CV(RMSE) (%)	7.8%	8.3%
eCALC DOE-2 Simulation	Energy Use	2,681	8,416
	MBE (%)	0.4%	-0.9%
	CVRMSE (%)	7.7%	8.4%
As-Built DOE-2 vs. eCALC DOE-2	Use Difference	-49	117
	% Difference	-1.8%	1.4%

SUMMARY

This paper compared the results of an As-Built DOE-2 calibrated simulation of a case-study building versus a simulation using the eCALC DOE-2 simulation program, which uses a simplified geometry for energy calculation. Both the As-Built and eCALC DOE-2 models used the same building characteristics from the JBC building except the building geometry (i.e., the As-Built DOE-2 simulation used as-is geometry and the eCALC DOE-2 simulation used a simplified box-shaped geometry). Both simulations showed uncertainties within the error range that ASHRAE has published. Also, the deviations of the energy consumption results between the As-Built and eCALC DOE-2 simulations were less than 2%.

ACKNOWLEDGEMENTS

Funding for this study was provided by Texas State Legislature through the Texas Emissions Reduction Program. The authors would like to thank Kelly Milligan and James Sweeney for their great support and cooperation during the process of metering and monitoring for data measurements. The authors also appreciate the support of this work from the Office of Energy Management at Texas A&M University.

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